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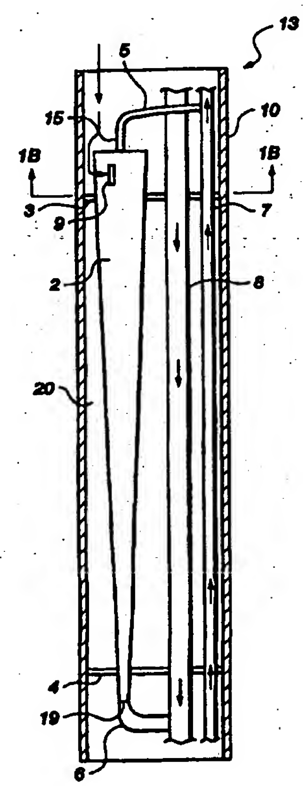
(54) Title: CYCLONIC SEPARATOR ASSEMBLY AND METHOD

(57) Abstract

Downhole apparatus (13) for separation of oil from oily water or water from oil having an internal chamber (20) continuously flooded with production fluids from a well, one or more hydrocyclonic separators (2) for separating the production fluid into a stream enriched in oil and a stream depleted in oil. The clearance required between the apparatus (13) and the well casing (17) being the minimum required for running the apparatus into the casing (17), maximizing the size of the separator(s) and improving capacity. A range of artificial lift devices is included to bring the oil enriched stream to the surface if the natural pressure of the reservoir is insufficient. Substantial axial overlap of multiple separators is provided for better compactness and capacity of the apparatus. Pipes (5) from separator overflow outlets connect to a common overflow manifold (7), and pipes (6) from the separator underflow outlets connect to a common underflow manifold (8). Where the space available for pipes (5, 6) and manifolds (7, 8) is limited adjacent to the separators the manifolds (7, 8) may be formed with a non-circular cross section having substantially the same cross-sectional area as adjacent portions of the manifold.



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CYCLONIC SEPARATOR ASSEMBLY AND METHOD

Field of the Invention

The present invention relates to apparatus and methods for the separation of liquids of differing densities in production streams from underground wells. More particularly, the invention relates to the downhole hydrocyclonic separation of a oil well or groundwater cleanup well production stream into two streams, a first stream enriched in oil relative to the production stream, and a second stream depleted in oil relative to the production stream, and transportation of the first, oil-enriched, stream to the surface.

Background of the Invention

Hydrocyclones are compact, centrifugal separators with no moving parts, which separate liquids in a liquid mixture. Hydrocyclones are widely used in both onshore and offshore oil production in above-ground applications such as bulk water knockout from produced fluids, de-oiling produced water prior to either water reinjection into a formation or water disposal to a disposal site. In these applications a plurality of hydrocyclones are typically mounted within a pressure vessel assembly. Such an assembly resembles a shell-and-tube heat exchanger, in that the hydrocyclones are mounted to tube sheets which are sandwiched between flanges in the pressure vessel. The complete pressure vessel assembly typically has a single inlet for the produced liquid stream, which comprises as for example, a mixture of oil and water and a plurality of outlets for the separated liquid streams. The assembly has an outlet for the "clean water" stream, which is relatively depleted in oil as compared to the production liquids, and an outlet for the "dry oil" stream, which is relatively enriched in oil as compared to the produced liquids.

Hydrocyclones, as they are employed in oil production and environmental cleanup applications are designed foremost to remove oil from water, that is, to produce a clean water stream with as low a concentration of oil as practicable. The dry oil stream will typically contain about 50 per cent water, by volume, and may contain more than 50 per cent water. Hydrocyclones, in a single-stage configuration, cannot produce both a completely water-free oil stream and a completely oil-free water stream; the design performance must be biased towards either the "dry oil" stream or the "clean water" stream. A clean water stream is obtained at the expense of "wet oil". Conversely, a dry oil stream is obtained at the expense of oily water. Hydrocyclone designs that are exemplary of those in the art are described in British Patent Application GB-A-2248198, which is incorporated herein by reference for all purposes, and U.S. Pat. No. 4,237,006, which is incorporated herein by reference for all purposes. Multi-stage separator assemblies including multiple hydrocyclones arranged in series, such as taught by U.S. Patent No. 4,738,779, incorporated herein by reference for all purposes, can achieve improved separation at the expense of increasing the pressure drop of the liquids moving through the multi-stage assembly.

Hydrocyclones are also useful for making a preliminary separation of oil from water in the production liquids produced downhole in an oil well prior to the production liquids being transported to the surface. This is of particular value in high water cut wells, with a high water content, where the production liquids may comprise about 70 per cent, or more, water. Conventionally, this water must be transported above ground, at significant cost and then disposed of, at additional expense. Hydrocyclone assemblies designed for above-ground use however, are not suitable for downhole applications where the assembly must be disposed within the bore hole of an oil well. This is because conventional hydrocyclone assemblies of sufficient capacity exceed

the size limitations imposed by the diameter of the well. Further, previous attempts to overcome these problems have resulted in additional complications.

For example, PCT International Application WO 94/13930 discloses a downhole separation apparatus in which one or more hydrocyclones are contained within an axially elongate tubular housing, with the inlet of each hydrocyclone extending through the wall of the housing and having an opening external of the housing. The separated dry oil and clean water streams from each hydrocyclone are transported from the housing by a relatively complex system of pipes. With this apparatus there must be sufficient clearance between the housing and the adjacent wall of the well casing to provide a flow annulus for transporting the production fluid to the hydrocyclone inlets. This limits the diameter of the hydrocyclone housing for a given size casing, and hence reduces the capacity of the separation apparatus. Further, the internal space within the housing, but outside of the separators and piping, is dry, so that there is a very substantial pressure differential across the walls both of the housing and the piping within the housing. Further, the housing must be tightly sealed against the full well bore pressure. This obviously requires the use of heavy gauge and/or specialty materials for construction of the housing, which results in increased costs for both materials and fabrication, and increases the risk of failure of the assembly.

In applications where the pressure of the liquids in the well bore is too low, pumps and associated pump driving equipment, are required. WO 94/13930 for example, discloses placing a pump on the clean water stream to assist in reinjection of the clean water into the formation. This does not address the important problem of transporting the dry oil stream to the surface however. U.S. Pat. No. 5,296,153 discloses pumping the dry oil stream to the surface and the clean water stream to

another formation. This further increases the cost and complexity of oil production, exacerbates the problem of locating the equipment within the well bore, and requires pumping the clean water stream, which increases both the capital and operating costs of oil recovery.

The present invention overcomes the deficiencies of the prior art.

Summary of the Invention

According to the present invention, there is provided a downhole separation assembly comprising an axially elongate tubular housing defining an internal chamber, and having at least one inlet which is arranged to allow production fluid to flood the chamber. At least one hydrocyclone separator is contained in the chamber and has an inlet open to the chamber so that the production fluid in the chamber enters each separator. An overflow outlet and an underflow outlet are provided for each separator, and are connected to pipes which lead out of the chamber.

By flooding the chamber containing the separator(s) in this way, it is unnecessary to provide a flow annulus between the housing and the well casing to supply production fluids to the separator inlet(s), so that the radial clearance between the walls of the housing and the well casing can be reduced to only that which is necessary to run the housing into the casing. To further reduce costs and further increase capacity, the well casing may be used as the housing, in which case the chamber is defined by the well casing and a pair of axially spaced packers which are well known in the art. The present invention thus allows the diameter of the tubular housing to be increased to nearly the diameter of the casing, thereby maximizing the capacity of the separation apparatus. Further, as there is a substantially reduced, and possibly no, pressure differential across the housing wall it is unnecessary to

provide the heavy gauge or specialty materials of the prior art to achieve the same structural integrity of the housing, and heavy duty seals are no longer required.

If the pressure in the well bore is low enough that the pumping of the production fluid is required prior to separation, the separation apparatus preferably includes a pumping unit which pumps production liquids into the chamber. A second pumping unit may also be provided, if necessary, to transport the dry oil stream to the surface. If, on the other hand, the pressure in the well bore is sufficiently high that no upstream pumping is required, the housing can be provided with a plurality of apertures so that the production fluid enters the housing at a plurality of locations along the length of the tubular housing. In this case, the size of the apertures may be smaller than the size of any of the passages within the housing and separator(s), to avoid a flow blockage of the separator(s) by any solid matter in the production fluid.

Preferably, a plurality of axially spaced separators are disposed in the chamber. In order to provide increased capacity, it may be desirable, in some cases, for adjacent separators to face in opposite directions, with some axial overlap between portions of adjacent separators. Where adjacent hydrocyclone separators do not face in opposite directions, substantial axial overlap may also be provided to maximize the compactness and hence the capacity of the separator assembly.

In order to reduce the complexity of the piping and seals required, it is desirable for the pipes leading from the overflow outlets of the separators to be connected to a common overflow outlet manifold within the chamber, and for the pipes which lead from the underflow outlets of the separators to be connected to a common underflow outlet manifold within the chamber.

For most applications, the overflow stream will leave the chamber at one end of the housing for transportation of a dry oil stream to the surface, while the underflow

stream will leave the chamber at the opposite end of the housing for transportation of a clean water stream for disposal downhole or elsewhere. If all of the overflow outlet pipes discharge through one end of the housing and/or all of the underflow outlet pipes discharge through the opposite end, it will be necessary for a pipe or manifold leading from the overflow outlet of a separator to extend past the separator or separators positioned above it in the chamber, and/or for a pipe or manifold leading from the underflow outlet of a separator to extend past the separator or separators positioned below it in the chamber. In this case, the space available for a pipe adjacent to the head of each hydrocyclone separator may be limited, because the head by its nature is the widest part of a hydrocyclone separator. At such locations, the pipe may be formed with a non-circular cross section having substantially the same cross-sectional area as do the adjacent portions of the pipe. For example, the non-circular cross section may be substantially kidney-shaped.

Examples of the more important features of the invention have been summarized broadly in order that the detailed description thereof that follows may be better understood, and in order that the contributions to the art may be better appreciated. There are, of course, additional features of the invention that will be described hereinafter and which will form the subject of the appended claims. These and various other characteristics and advantages of the present invention will be readily apparent to those skilled in the art upon reading the following detailed description of the preferred embodiments of the invention and by referring to the accompanying drawings.

Other objects and advantages of the invention will appear from the following description.

BRIEF DESCRIPTION OF THE DRAWINGS

For a detailed description of a preferred embodiment of the invention, reference will now be made to the accompanying drawings, wherein:

Figure 1A is a schematic which depicts a down hole hydrocyclone separator assembly in accordance with the present invention shown in a simplified axial cross-section as having a single hydrocyclone;

Figure 1B is a schematic illustration of the embodiment of the invention depicted in Figure 1A, in radial cross-section taken through section 1B-1B;

Figure 2A depicts a schematic representation of an embodiment of the present invention which includes a first pump for the produced liquids stream and a second pump for the dry oil stream and illustrates an exemplary arrangement of the apparatus within a well bore;

Figure 2B depicts in axial cross-section a schematic representation of a first sub in accordance with the embodiment of the invention illustrated in Figure 2A;

Figure 2C depicts in axial cross-section a schematic representation of a second sub in accordance with the embodiment of the invention illustrated in Figure 2A;

Figure 2D depicts in axial cross-section a schematic representation of a third sub in accordance with the embodiment of the invention illustrated in Figure 2A;

Figures 3A and 3B are each broken axial section views of portions of a down hole hydrocyclone separator assembly in accordance with the present invention and illustrate an assembly with two hydrocyclones and associated piping and connections;

Figure 4A, 4B, and 4C are each broken axial section views of portions of a down hole hydrocyclone separator assembly in accordance with the present invention and illustrate an assembly with five hydrocyclones and associated piping and connections;

Figure 4D is a radial cross-section view of the embodiment illustrated in Figure 4A taken through section A-A; and

Figure 4E is a radial cross-section view of the embodiment illustrated in Figure 4B taken through section B-B.

DESCRIPTION OF THE PREFERRED EMBODIMENTS

For purposes of illustration and not by way of limitation, the present invention is described with respect to several exemplary down hole hydrocyclone separator assemblies for separating the produced liquids from a well into a dry oil stream and a clean water stream, with satisfactory capacity, compactness, and cost, for application to conventional high cut oil wells in oil production or environmental cleanup.

Referring now to Figures 1A and 1B, there is shown a simplified schematic diagram of a first preferred embodiment of the hydrocyclone separator assembly of the present invention comprising a single hydrocyclone. The separator assembly, denoted generally by reference numeral 13, preferably comprises a housing 10, a hydrocyclone 2, and an internal chamber 20 defined by the inside diameter of housing 10. Optionally, upper and lower support plates 3 and 4, respectively, may be provided for supporting the piping and hydrocyclone 2 within chamber 20. If support plates 3 and 4 are used, production openings 11 are provided in support plates 3 and 4 so that internal chamber 20 remains open to the production liquids. An overflow manifold 7 and an underflow manifold 8 extend through chamber 20 and are preferably provided when multiple separator assemblies are disposed in the well. Manifolds 7 and 8 are both firmly affixed to both support plates 3 and 4.

Hydrocyclone 2 is preferably of a well known de-oiling configuration such as that described in British Patent Application GB-A-2248198, and has one or more

tangential inlets 9 which are open to the interior of the housing 10. An underflow pipe 6 is hydraulically connected to the underflow outlet 19 of the hydrocyclone separator 2, and is hydraulically connected to the underflow manifold 8. Similarly, an overflow outlet pipe 5 is connected to the overflow outlet 15 of hydrocyclone separator 2, and is connected to the overflow manifold 7. In operation, one or more separator assemblies 13 are run into the cased well bore with minimal clearance between the exterior wall of housing 10 and the interior wall of the well casing. Production fluid, which has either been pressurized by a pump or is naturally under pressure, floods the internal chamber 20, and enters hydrocyclone separator 2 through separator inlet(s) 9. If support plates 3 and 4 are provided, production fluid floods chamber 20 by flowing through production openings 11. The production fluid is caused to swirl within hydrocyclone 2 by the tangential orientation of inlet(s) 9. In hydrocyclone separator 2, the production fluid is separated into a clean water stream which flows to the underflow and a dry oil stream which flows to the overflow as is well known in the art. As noted above, the clean water stream is enriched in water relative to the production liquid stream, while the dry oil stream is enriched in oil relative to the production stream. The underflow from the hydrocyclone separator 2 flows through the underflow outlet pipe 6 to underflow manifold 8, and is preferably transported downhole below assembly 13 for disposal or reinjection into the formation. The dry oil from the overflow outlet 15 flows up through the overflow outlet pipe 5 to overflow manifold 7, and then to the surface where it may be further treated. In applications where a single hydrocyclone assembly is disposed within the oil well, underflow pipe 6 is preferably connected to a disposal pipe (not shown) below housing 10, whereby manifolds 7 and 8 are no longer necessary.

Referring now to Figure 2A, there is shown a schematic representation of a second preferred embodiment of the separator assembly of the present invention including a plurality of the separator assemblies 13 shown in Figure 1A. Separator assemblies 13 are disposed between two axially spaced packers, a lower packer 93 and an upper packer 95. Upper packer 95 is optional. Upper packer 95 is used when an upper formation is isolated from the formation having perforations 90; when the disposal liquid, such as water, is to be disposed above the separator assembly; or when it is desirable to prevent the production fluids from perforations 90 from flowing up hole. Two such separator assemblies, top separator assembly 13A and bottom separator 13B are shown, although any number of separator assemblies 13 may be used without departing from the scope of the present invention. It should be appreciated that separator assemblies 13A and 13B are substantially the same as separator assembly 13 described with respect to Figure 1A, and like reference numerals will be used for like parts with the designation A or B for upper and lower assemblies 13A and 13B, respectively.

A production pump 31 is provided for pumping the production fluids and an overflow pump 32 is provided for pumping the overflow (dry oil) stream to the surface. Pumps 31 and 32 are driven by drive means such as one or more drive motors 30. For illustration and not by way of limitation, pumps 31 and 32 may be electric submersible pumps, progressive cavity pumps, or beam (or rod) pumps, all of which are well known in the art. Many other types and combinations of pumps and drive systems may be successfully used in accordance with the present invention, such as jet pumps and gas lift systems. As will be readily apparent to one skilled in the art, a range of artificial lift systems may be used in conjunction with the natural reservoir pressure without departing from the scope of the present invention.

Pumps 31, 32 and drive motor 30 are preferably disposed above separator assemblies 13A, 13B to simplify connection to a power source (not shown) which supplies electric or hydraulic power to drive motor 30. Other arrangements of pumps 31, 32 and drive motor 30 with respect to separator assemblies 13A and 13B are, of course, possible without departing from the scope of the invention.

While the embodiment of the invention described with respect to Figure 2A illustrates only two separator assemblies 13A and 13B, any number of such assemblies may be used in conjunction with the apparatus described immediately below. Separator assemblies 13 are thus modular, and the number of such modules used should be determined in practice by the desired overall capacity, available reservoir pressure, and choice and design of pumps.

Referring now to Figure 2B, a first or top sub 41 is preferably disposed between drive motor 30 and the separator assembly 13A, as shown in Figure 2A, and hydraulically seals around its periphery to well casing 17. Sub 41 preferably includes a passage 111 for the production fluids being pumped, an overflow passage 71, and a blind bore 81 for receiving one end of underflow manifold 8A to prevent upward passage of the underflow stream. Passage 111 allows the production fluids from the outlet of production pump 31 to flow to separator assembly 13A. Overflow passage 71 in sub 41 interconnects the overflow manifold 7A (shown in Figure 1A) of separator assembly 13A to a dry oil conduit means (not shown) extending to the surface through which the dry oil is transported to overflow pump 32. Blind bore 81 of sub 41 hydraulically seals off one end of underflow manifold 8A.

Referring now to Figure 2C, a second or connecting sub 42 preferably is disposed between any two of separator assemblies 13, such as separator assemblies 13A and 13B, as shown in Figure 2A for connecting adjacent assemblies. Sub 42

preferably includes a passage 211 for the pumped production fluids, an overflow passage 72, and an underflow passage 82. Passage 211 hydraulically interconnects the two separator assemblies 13A and 13B adjacent to sub 42 for the flow of production fluids. Thus the production fluids may pass freely between internal chambers 20A and 20B of separator assemblies 13A and 13B. Overflow passage 72 hydraulically interconnects the overflow manifolds 7A and 7B of any two separator assemblies 13 adjacent to sub 42, such as top separator assembly 13A and bottom separator assembly 13B. Similarly, underflow passage 82 hydraulically interconnects the underflow manifolds 8A and 8B of the two separator assemblies 13 adjacent to sub 42.

Referring now to Figure 2D, a third or bottom sub 43 preferably is disposed between the bottom separator assembly 13B and lower packer 93. Sub 43 preferably includes underflow passage 83, which terminates at its lowest end in a threaded pipe box 80. Underflow passage 83 hydraulically connects the underflow manifold 8B of the bottom separator assembly 13B to a disposal pipe 84, shown in Figure 2A.

Referring again to Figure 2A, in operation, production fluids enter the annulus 85 formed between housing 10 and well casing 17 through production perforations 90 in casing 17. The production fluids are drawn into production pump 31 and pumped through production passage 111 of first sub 41 to top separator assembly 13A. Should optional support plates 3A and 4A be used the production fluids flood chamber 20A by passing through production openings 11A. (See Figure 1A). The production fluids also pass through production passage 211 in second sub 42 and, as above, flood the internal chamber 20B of bottom separator assembly 13B below sub 42. In this way, the internal chamber 20 of each of the separator assemblies 13 is flooded with production fluids.

As described above with reference to Figure 1A, the production fluids are separated by the hydrocyclones 2A and 2B, with the overflow streams passing into overflow manifolds 7A and 7B and the underflow streams passing into underflow manifolds 8A and 8B. The overflow manifolds 8A and 8B of the several separator assemblies 13A and 13B form a continuous manifold by virtue of passage 72 through sub 42. The overflow thus flows up through overflow manifolds 7A and 7B, through overflow passage 72 of sub 42, through overflow passage 71 of sub 41, to overflow pump 32, which then pumps the overflow through recovery pipe 74 extending to the surface. In wells with sufficient natural reservoir pressure, overflow pump 32 is not required.

Similarly, the underflow manifolds 7A and 7B of the several separator assemblies 13A and 13B form a continuous manifold by virtue of passage 82 through sub 42. The underflow is prevented, by blind bore 81 in sub 41, from passing up the well. The underflow from all the separator assemblies 13 therefore finally exits via passage 83 in sub 43 and disposal pipe 84, and may then be injected into the formation via injection perforations 96, located in the well casing 17 anywhere below lower packer 93. It should be understood that although the embodiment of the invention described with reference to Figure 2A includes two separator assemblies 13A and 13B, any number of modular separator assemblies 13 may be used without departing from the scope of the present invention.

Referring now to Figures 3A and 3B, there is shown a third preferred embodiment of the hydrocyclone separator assembly of the present invention, generally denoted by reference numeral 113, which includes two hydrocyclones. The separator assembly 113 comprises a housing 100 defining an internal chamber 120 which is sealed at an upper end by a first sealing block 102 and at a lower end by a

second sealing block 103. The separator assembly may be reversible, in which case first sealing block 102 seals the lower end and second sealing block 103 seals the upper end. A production fluid inlet may be provided to separator assembly 113 in either of two ways. First, if a production fluid pump is provided above the first sealing block 102 (such as production pump 31 shown in Figure 2A) or below the second sealing block 103, an inlet 161A into the chamber 120, such as is shown in first sealing block 102, is preferably provided through the appropriate sealing block. On the other hand, if no pump is required, the housing 100 is preferably provided with a plurality of apertures, such as holes 161B, or slots (not shown) which allow direct access for the production fluid into the chamber 120. As will be apparent to one skilled in the art, alternative types of apertures may be provided without departing from the scope of the present invention.

An upper hydrocyclone separator 104 and a lower hydrocyclone separator 105, preferably are arranged in parallel within housing 100. The hydrocyclone separators 104 and 105 have a de-oiling configuration which is well known in the art. Both separators 104 and 105 have one or more tangential inlets 106 which are open to the interior of separators 104 and 105. Although the inlets are illustrated as being in the plane of the section, this is only for clarity and, in practice, the inlets will generally be out of this plane.

An underflow pipe 107 is connected to the underflow outlet 115 of the upper hydrocyclone separator 104 and leads down the chamber 120 past the lower separator 105. In the region adjacent to the head 117 of the lower separator 105, the first underflow outlet pipe is provided with a non-circular portion 107A which, in plan, may have a substantially kidney-shaped cross section. This cross-sectional configuration ensures that the cross-sectional area of the pipe underflow pipe 107

remains substantially unchanged as the non-circular portion 107A of underflow pipe 107 passes the head of lower separator 105, despite the limited space available adjacent to the head 117 of the second separator 105. Of course, where not required by space limitations, non-circular portion 107A is not necessary, so long as the cross-sectional area of underflow pipe 107 is maintained substantially constant. It should also be appreciated that non-circular portion 107A may include a plurality of pipes extending between outlet 115 and the main tubular portion 107B of pipe 107, it being important that the cross-sectional flow area is substantially the same around head 117 as with portion 107A. However, multiple pipes are not preferred because they take up more area within housing 100 than non-circular portion 107A. The underflow outlet pipe 107 leads to a manifold 108 which is shown as a part of the second sealing block 103. The underflow outlet 119 of the lower separator 105 is also connected to manifold 108 so that the underflow streams from the two separators 104, 105 are combined prior to passing through second sealing block 103.

Similarly, an overflow outlet pipe 109 leads from the outlet 121 of lower separator 105 past the upper separator 104, and the overflow stream from lower separator 105 combines with the overflow stream from outlet 110 of the upper separator 104 in a manifold (not shown) similar to manifold 108, which then passes through first sealing block 102.

It should be appreciated that it is most desirable to maximize the size of the head 117 of the separators within housing 100, or casing 17 if no separate housing is utilized for the separator assembly, to maximize the separation capacity of each separator. However, the remaining cross-sectional area around head 117 must accommodate not only underflow manifold 107 and overflow manifold 108 but must

also leave adequate flow area for the production fluids flowing by head 117 to feed other separators in the assembly.

The construction of the separator assembly 113 (as well as separator assembly 13, Figure 1A) is preferably simplified by the use of many standard pipe sections as are well-known in the art, and hydrocyclones of de-oiling configurations, also well known in the art. Generally, the only specialty parts required are the first sealing block 102 and the second sealing block 103, the non-circular pipe section 107A (if necessary), and an adapter 213 provided between the two separators 104, 105 for connecting separator outlets 107, 121 to corresponding pipes.

In operation, running the separator assembly 113 into a well bore preferably requires only minimal clearance between the walls of housing 100 and the well casing, i.e., only enough clearance to run the assembly through the well casing. For example, the diametrical clearance may be as small as one sixteenth of an inch. No clearance is required for the flow of production fluids, as in the prior art, since chamber 20 is open to the flow of production fluids. Production fluids flood the internal chamber 120 through the alternative production fluid inlets described above. The production fluids in the internal chamber 120, which have been either pressurized by a pump or is naturally under pressure, enters the two separators 104, 105 through respective separator tangential inlets 106, and is caused to swirl by the tangential orientation of inlets 106. In the separators 104, 105 the production fluids are separated into a clean water stream which flows to the underflow and a dry oil stream which flows to the overflow. As noted above, the clean water stream is enriched in water relative to the production fluids, while the dry oil stream is enriched in oil relative to the production fluids. In the embodiment illustrated in Figures 3A and 3B, the underflow from the two separators flows through the second sealing block 103, and

may then be transported downhole for disposal or reinjection via outlet 184. The dry oil stream from the overflow flows up through the first sealing block 102 and then to the surface where it may be further treated.

Although the embodiment described above has only two hydrocyclone separators, further separators can be used if required. In this case, a common underflow outlet pipe is preferably progressively larger in cross-sectional area as it extends down the chamber 120 because the underflow outlet streams from further separators join the common underflow outlet pipe substantially increasing the volume of flow. Similarly, a common overflow outlet pipe is preferably progressively larger in cross-sectional area as it extends up the chamber, because the overflow outlet streams from further separators join the common overflow outlet pipe also increasing the volume of flow.

With respect to the embodiment of the separator assembly described above with reference to Figures 3A and 3B, the outside diameter of housing 100 is preferably less than the inside diameter of the well casing by only the clearance necessary to run the assembly 113 into the well. For example, the diametrical clearance may be approximately one-sixteenth of an inch. This maximizes the diameter of the separator assembly and housing, and maximizes the size of separators 104 and 105, thereby maximizing the capacity of the entire separator assembly.

For example, assemblies such as assembly 113 having two hydrocyclones in accordance with the embodiment described above have been constructed and tested where the outside diameter of housing 100 is 4.5 inches and the length of housing 100 is about 13 feet. Such an assembly is suitable for use in 5 inch well casing having an inside diameter of 4-9/16 inches. A capacity of up to 4,000 barrels of

production fluid per day may be achieved with such a two hydrocyclone assembly. The cross-sectional area of the head of each hydrocyclone 104 and 105 may be one-half or greater than the cross-sectional area of the housing 100. It is preferable to maximize this ratio to maximize the capacity of the separator assembly. The remaining cross-sectional area of housing 100 is used for manifolds 107, 108 and the flow of production fluids.

Referring now to Figures 4A - 4E, there is shown a fourth preferred embodiment of the hydrocyclone separator assembly of the present invention which includes five hydrocyclones, and is denoted generally by reference numeral 313. The separator assembly 313 comprises a tubular housing 300 defining an internal chamber 320 which is sealed at an upper end by a top adapter 310 and at a lower end by a bottom adapter 380. Top adapter 310 and bottom adapter 380 are secured to housing 300 by threaded collars 311 and 321, respectively. Separator assembly 313 may alternatively be reversed, so that adapter 310 is disposed at the lower end and adaptor 380 is disposed at the upper end.

A production fluid inlet may be provided in either of two ways. First, if a production fluid pump is provided above the top adapter 310 (such as production pump 31 shown in Figure 2A) or below the bottom adapter 380, an inlet 361A into the chamber 320 is provided through the appropriate adapter, such as shown in adapter 310. On the other hand, if no pump is required, the housing 300 may be provided with a plurality of apertures, such as holes 361B, or slots (not shown), or screened openings (not shown), which allow direct access of the production fluids into the chamber 320. As one skilled in the art will immediately understand, other means of providing the plurality of apertures may be employed without departing from the scope of the invention.

The five hydrocyclone separators, denoted in order moving from the top adapter 310 to the bottom adapter 380 by reference numerals 301, 302, 303, 304, and 305, are preferably arranged in parallel within housing 300. Once again, the hydrocyclone separators have a well known de-oiling configuration as is well known in the art. Each of the separators has one or more tangential inlets (not shown, but substantially similar to inlets 106 described above with reference to Figures 3A and 3B) which are open to the interior of the separators.

An underflow pipe 360 connects each of the underflow outlets of the hydrocyclone separators 302, 303, and 304, to an underflow manifold 340. For example, an underflow pipe 360A connects the underflow outlet of the top hydrocyclone 301 to underflow manifold 340. Underflow pipe 360A may vary slightly in its cross-sectional configuration from underflow pipes 360 because underflow pipe 360A forms the top inlet of underflow manifold 340. Underflow manifold 340 extends down through the chamber 320 and past the lowest hydrocyclone 305, into bottom adapter 380. The underflow from hydrocyclone 305 also leads to bottom adapter 380, so that the underflow stream from all of the hydrocyclone separators 301 - 305 is combined prior to passing through bottom adapter 380. The underflow from hydrocyclone 305 communicates with the bore 381 of bottom adapter 380, as does underflow manifold 340.

Referring now to Figures 4A, 4B, 4C and 4E, in the region adjacent to the heads 117 of hydrocyclone separators 302, 303, 304, and 305, the underflow manifold 340 may be provided with a non-circular portion 340A which, in plan, may have a substantially kidney-shaped cross section (See Figure 4E). Although shown as substantially kidney-shaped in cross-section, non-circular portion 340A may have any cross-sectional configuration that ensures that its cross sectional area at the

standard circular portion 340B remains substantially unchanged as the non-circular portion 340A of underflow manifold 340 passes the head 117 of separators 302 - 305, despite the limited space available. It should also be appreciated that the underflow manifold 340 and overflow manifold 330 shown in Figure 4E adjacent head 117 of a separator may be cast into one piece which includes two flow passages therethrough, one for overflow and another for underflow. A one piece casting further reduces the cross-sectional area required to by-pass head 117 by manifolds 330, 340. If space limitations do not require it, non-circular portion 340A need not be provided.

Similarly, overflow outlet pipes 370 connect the overflow outlet of each of the separators 301 - 305 with overflow manifold assembly 330, similar to manifold 340, which extends through top adapter 310. Underflow manifold assembly 340 is preferably substantially larger in cross-sectional area than that of overflow manifold assembly 330 to accommodate the relatively larger flow rate of the underflow stream. For example, separation apparatus in accordance with the embodiment of Figures 4A - 4E, has been successfully used with the cross-sectional area of the underflow manifold assembly 340 being up to four times larger than the cross-sectional area of the overflow manifold assembly 330. Further, those sections 340B of underflow manifold 340 extending between the underflow outlets of adjacent separators may increase in diameter from separator 301 to separator 305 since the largest volume of flow will occur through underflow manifold 340 adjacent the outlet of lowermost separator 305.

The outside diameter of housing 300 is preferably less than the inside diameter of the well casing by only the clearance necessary to run the assembly into the well, for example a diametrical clearance of one-sixteenth of an inch may be used. This maximizes the diameter of the housing 300 which, in turn, maximizes the size of

hydrocyclone separators 301 - 305, thereby maximizing the capacity of the entire separator assembly. The well casing diameter may be measured prior to running the housing into the well, to ensure sufficient clearance is present. Alternatively, housing 300 may comprise the well casing itself, which further increases the diameter of separator assembly 313 and increases capacity.

The construction of the separator assembly described above is preferably simplified by the use of standard pipe sections and standard de-oiling hydrocyclones, as described previously. The specialty parts required may include the top adapter 310, bottom adapter 380, the non-circular portions 340A (if necessary) of underflow manifold 340, underflow pipes 360 and 360A, and overflow pipes 370. As can be seen from a comparison of Figure 3B and Figure 4B, adapter 211 as described with reference to Figure 3B is not required between adjacent hydrocyclone separators in the assembly configuration of the embodiment described with reference to Figure 4B.

In use, the installation and operation of separator assembly 313 is as described above with reference to separator assembly 113, which is illustrated in Figures 3A and 3B. Separator assembly 313 is capable of substantially greater capacity than assembly 113.

For example, assemblies such as assembly 313 having five standard sized hydrocyclones in accordance with the embodiment described above have been constructed and tested where the diameter of housing 300 is 5.5 inches and the length of housing 300 is about 24 feet. Such an assembly is suitable for use in 7 inch well casing. A capacity of up to 10,000 barrels of production fluid per day can be achieved with such a five hydrocyclone assembly. The ratio of the cross-sectional area of the head of hydrocyclones 301 - 305 to the cross-sectional area of the housing 300 is about 0.3 or greater. This ratio is smaller than 0.5 because standard-

sized hydrocyclones were used. It is preferable to maximize this ratio to maximize the capacity of the separator assembly.

While it is possible to create a modular system by combining two or more separator assemblies 313 with appropriate manifold connections, this becomes increasingly difficult as the number of hydrocyclone separators increases. This is because the piping and manifolding required exceeds the space available within housing 300, particularly at the lower end of the housing 300, for a given well casing diameter, when the number of hydrocyclones exceeds a certain value.

While a preferred embodiment of the invention has been described, modifications thereof can be made by one skilled in the art without departing from the spirit of the invention.

CLAIMS:

1. Apparatus disposed down hole in an oil well casing, comprising:

a tubular housing having a chamber which is in fluid communication with, and at least partially flooded with, production fluids produced in the well;

a hydrocyclone assembly disposed within the housing for separating the production fluids into a less dense overflow fluid stream and a more dense underflow fluid stream, said assembly having a separation chamber with a head portion in the form of an axially extending surface of revolution of substantially uniform configuration and a contiguous tail portion in the form of an axially extending surface of revolution of generally tapered configuration, said head portion being of greater diameter than said tail portion and having a tangential production fluid inlet for the flow of the production fluids into the separation chamber and an overflow outlet for the flow of the overflow fluid stream from the separation chamber, said tail portion being of lesser diameter than the head portion and having an underflow outlet for flow of the underflow fluid stream from said separation chamber;

an overflow fluid manifold extending through said housing and connected to said overflow outlet for receiving the overflow fluid stream from said hydrocyclone assembly;

an underflow fluid manifold extending through said housing and connected to said underflow outlet for receiving the underflow fluid stream from said hydrocyclone assembly.

2. The apparatus of claim 1, wherein the housing comprises the oil well casing.

3. The apparatus of claim 1, wherein the housing has an outside diameter which is substantially equal to the difference between the diameter of the well casing and a running clearance for insertion of the housing within the well casing.

4. The apparatus of claim 3, wherein the running clearance is approximately one-eighth of an inch.

5. The apparatus of claim 1, wherein the underflow fluid manifold has a substantially greater cross sectional area for flow than does the overflow fluid manifold.

6. The apparatus of claim 3, wherein the underflow fluid manifold has a substantially greater cross sectional area for flow than does the overflow fluid manifold.

7. The apparatus of claim 6, wherein the underflow fluid manifold has a cross-sectional area for flow that is approximately four times as great as that of the overflow fluid manifold.

8. The apparatus of claim 3, further comprising:

a production fluid pump, disposed down hole, for pumping production fluids into the housing.

9. The apparatus of claim 8, further comprising:

an overflow fluid pump, disposed down hole, for pumping the overflow fluid stream above ground;

overflow fluid pump drive means for driving the overflow fluid pump.

10. The apparatus of claim 8, wherein the production fluid pump is an electric submersible pump.

11. The apparatus of claim 8, wherein the production fluid pump is a progressive cavity pump.

12. The apparatus of claim 9, wherein the production fluid pump and the overflow fluid pump are electric submersible pumps.

13. The apparatus of claim 9, wherein the production fluid pump and the overflow fluid pump are progressive cavity pumps.

14. The apparatus of claim 9, wherein the production fluid pump and production fluid pump drive means, and the overflow fluid pump and overflow fluid pump drive means are disposed above the housing and downhole within the oil well casing.

15. The apparatus of claim 1, further comprising a housing production inlet, open to the separation chamber and disposed at an end of the housing, and through which the production fluids pass to the tangential fluid inlet of the hydrocyclone assembly.

16. The apparatus of claim 1, further comprising a housing production inlet, comprising a plurality of apertures in a peripheral wall of the axially elongate tubular housing.

17. The apparatus of claim 1, further comprising a housing production inlet, comprising an aperture in a peripheral wall of the axially elongate tubular housing.

18. Apparatus comprising:

a tubular housing disposed downhole within an oil well casing, and which is in fluid communication with, and at least partially flooded with, production fluids;

a first hydrocyclone assembly disposed within the housing for separating a production fluid stream into a less dense overflow fluid stream and a more dense underflow fluid stream comprising: a first separation chamber having a first head portion in the form of an axially extending surface of revolution of

substantially uniform configuration and a first contiguous tail portion in the form of an axially extending surface of revolution of generally tapered configuration, the first head portion being of greater diameter than the first tail portion, and having a tangential production fluid inlet for inlet of the production fluid stream into the first separation chamber, and further having a first overflow outlet for outlet of the overflow fluid stream from the first separation chamber, the first tail portion having a first underflow outlet for outlet of the underflow fluid stream from the first separation chamber;

a second hydrocyclone assembly disposed within the housing, for separating the production fluid stream into the more dense overflow fluid stream and the less dense underflow fluid stream comprising: a second separation chamber having a second head portion in the form of an axially extending surface of revolution of substantially uniform configuration and a second contiguous tail portion in the form of an axially extending surface of revolution of generally tapered configuration, the second head portion being of greater diameter than the second tail portion, and having a tangential production fluid inlet for inlet of the production fluid stream into the second separation chamber, and further having a second overflow outlet for outlet of the overflow fluid stream from the second separation chamber, the second tail portion having a second underflow outlet for outlet of the underflow fluid stream from the second separation chamber;

an overflow fluid manifold disposed substantially within the housing for receiving the overflow fluid stream from the first and second overflow fluid outlets, said overflow manifold having a substantially constant cross-sectional area; and

an underflow fluid manifold disposed within the housing for receiving the underflow fluid stream from the first and second underflow outlets, said underflow manifold having a substantially constant cross-sectional area.

19. The apparatus of claim 18 wherein the cross-section of the underflow fluid manifold is, in part, substantially kidney-shaped.

20. The apparatus of claim 18 wherein the head portion of the second hydrocyclone assembly axially overlaps with the first contiguous tail portion of the first hydrocyclone assembly.

21. The apparatus of claim 20 wherein the difference between the diameter of the well casing and the outside diameter of the housing is approximately equal to a clearance for running the housing into the well casing.

22. The apparatus of claim 21 wherein the clearance is approximately one-eighth of an inch.

23. The apparatus of claim 21 wherein the clearance is less than one-eighth of an inch.

24. Apparatus disposed downhole within an oil well casing, comprising:

a tubular housing of substantially circular cross section, and which is in fluid communication with, and at least partially flooded with, production fluids;

a first hydrocyclone assembly disposed within the housing, for separating a production fluid stream into a less dense overflow fluid stream and a more dense underflow fluid stream, comprising: a first separation chamber having a first head portion in the form of an axially extending surface of revolution of substantially uniform configuration and a first contiguous tail portion in the form of an axially extending surface of revolution of generally tapered configuration, the first head portion being of greater diameter than the first tail portion, and having a

tangential production fluid inlet for inlet of the production fluid stream to the first separation chamber, and further having a first overflow outlet for outlet of the overflow fluid stream from the first separation chamber, the first tail portion having a first underflow outlet for outlet of the underflow fluid stream from the first separation chamber;

a second hydrocyclone assembly disposed within the housing, for separating the production fluid stream into a more dense overflow fluid stream and a less dense underflow fluid stream, comprising: a second separation chamber having a second head portion in the form of an axially extending surface of revolution of substantially uniform configuration and a second contiguous tail portion in the form of an axially extending surface of revolution of generally tapered configuration, the second head portion being of greater diameter than the second tail portion, and having a tangential production fluid inlet for inlet of the production fluid stream to the second separation chamber, and further having a second overflow outlet for outlet of the overflow fluid stream from the second separation chamber, the second tail portion having a second underflow outlet for outlet of the underflow fluid stream from the second separation chamber;

one or more third hydrocyclone assemblies disposed within the housing between the first and second hydrocyclone assemblies, for separating the production fluid stream into a more dense overflow fluid stream and a less dense underflow fluid stream, each third hydrocyclone assembly comprising: a third separation chamber having a third head portion in the form of an axially extending surface of revolution of substantially uniform configuration and a third contiguous tail portion in the form of an axially extending surface of revolution of generally tapered configuration, the third head portion being of greater diameter than the third tail portion, and having a

tangential production fluid inlet for inlet of the production fluid stream to the third separation chamber, and further having a third overflow outlet for outlet of the overflow fluid stream from the third separation chamber, the third tail portion having a third underflow outlet for outlet of the underflow fluid stream from the third separation chamber;

an overflow fluid manifold disposed substantially within the housing for receiving the overflow fluid stream from the first overflow fluid outlet of the first hydrocyclone assembly and for receiving overflow fluid stream from the second overflow fluid outlet from the second hydrocyclone assembly, and for receiving the overflow fluid stream from the third overflow fluid outlet from each of the third hydrocyclone assemblies, said overflow manifold having a substantially constant cross-sectional area;

an underflow fluid manifold disposed within the housing for receiving the underflow fluid stream from the first underflow outlet of the first hydrocyclone assembly and for receiving the underflow fluid stream from the second underflow outlet of the second hydrocyclone assembly and for receiving the underflow fluid stream from the third underflow outlet of each of the third hydrocyclone assemblies; and

a housing production inlet, comprising a plurality of apertures in a peripheral wall of the axially elongate tubular housing.

25. The apparatus of claim 24, wherein the underflow manifold has a substantially constant cross-sectional area.

26. The apparatus of claim 24, wherein the a first portion of the underflow manifold has a first cross-sectional area and a second portion of the underflow

manifold has a second cross-sectional area, said second cross-sectional area being substantially greater than said fort cross-sectional area.

27. The apparatus of claim 26, wherein the second portion of the underflow manifold further comprises an overlap portion wherein there is substantial axial overlap between the overlap portion of the underflow manifold and the head portion of the second hydrocyclone assembly.

28. The apparatus of claim 27, wherein the overlap portion of the underflow manifold has a non-circular cross-section for flow.

29. The apparatus of claim 27, wherein the overlap portion of the underflow manifold has a substantially kidney-shaped cross-section for flow.

30. The apparatus of claim 28, further comprising:

a first overflow pipe in connection with the first overflow outlet and also in connection with the overflow fluid manifold, and through which the overflow fluid stream flows from the first overflow outlet to the overflow fluid manifold;

a second overflow pipe in connection with the second overflow outlet and also in connection with the overflow fluid manifold, and through which the overflow fluid stream flows from the second overflow outlet to the overflow fluid manifold;

one or more third overflow pipes in connection with each of the third overflow outlets and also in connection with the overflow fluid manifold, and through which the overflow fluid streams flow from each of the third overflow outlets to the overflow fluid manifold;

a first underflow pipe in connection with the first underflow outlet and also in connection with the underflow fluid manifold, and through which the underflow fluid stream flows from the first underflow outlet to the underflow fluid manifold;

a second underflow pipe in connection with the second underflow outlet and also in connection with the underflow fluid manifold, and through which the underflow fluid stream flows from the second underflow outlet to the underflow fluid manifold;

one or more third underflow pipes in connection with each of third underflow outlets and also in connection with the underflow fluid manifold, and through which the underflow fluid streams flow from each of the third underflow outlets to the underflow fluid manifold.

31. The apparatus of claim 27, wherein there is substantial axial overlap between the overflow outlet pipe of the second hydrocyclone assembly and the underflow outlet pipe of one or more of the third hydrocyclone assemblies.

32. The apparatus of claim 31, wherein the housing has an outside diameter that is approximately the difference between an inside diameter of the well casing and a clearance for running the housing into the well casing.

33. The apparatus of claim 32 wherein the clearance is approximately one-eighth of an inch.

34. The apparatus of claim 31, wherein there is substantial axial overlap between the underflow outlet pipe of the first hydrocyclone assembly and the third head portion of one or more of the third hydrocyclone assemblies.

35. An apparatus disposed downhole in the casing of a well for separating a recovery liquid from the mixed liquids produced by the well, comprising:

a pipe for flowing the recovery liquid to the surface from the well;

a cyclone separator disposed on said pipe within the casing for separating the recovery liquid from the mixed liquids, said separator having an inlet

open to the casing for the flow of mixed liquids, an outlet connected to said pipe for the recovery liquid, and an outlet member for the disposed liquids;

a packer disposed around said outlet member for flowing the disposed liquids below said packer; and

said packer sealingly engaging the casing.

36. An apparatus disposed in the borehole of a well for separating a recovery liquid from the mixed liquids produced by the well, comprising:

a tubular housing forming a chamber;

a cyclone separator disposed within said chamber for separating the recovery liquid from the mixed liquids, said separator having an inlet for the mixed liquids, a first outlet for the recovery liquid, and a second outlet for the disposed liquids;

a first manifold connected to said first outlet for flowing the recovery liquid from the well to the surface;

a second manifold connected to said second outlet for flowing the disposed liquids into the borehole of the well; and

a first pump disposed in the borehole and connected to said first manifold for pumping the recovery liquid to the surface.

37. The apparatus of claim 36, further including a second pump disposed in the borehole and connected to said inlet for pumping the mixed liquids into said separator.

38. An apparatus disposed in the borehole of a well for separating a recovery liquid from the mixed liquids produced from the formation in the well, comprising:

a tubular housing forming a cylindrical chamber, said chamber being open to the flow of the mixed liquids;

a plurality of cyclone separators disposed within said chamber for separating the recovery liquid from the mixed liquids, each said separator having an inlet for allowing the mixed liquids in said chamber to flow into each said separator, a first outlet for the recovery liquid, and a second outlet for the disposed liquids;

a first manifold connected to each of said first outlets for flowing the recovery liquid to the surface of the well; and

a second manifold connected to each said second outlet for removing the disposed liquids.

39. The apparatus of claim 38, wherein said second manifold increases in flow area in the direction of flow of the disposed liquids.

40. The apparatus of claim 39 wherein said second manifold has sized sections for each said separator with said sized sections increasing in cross-sectional area in the direction of flow of the disposed liquids.

41. The apparatus of claim 38, wherein said first manifold has a constant flow area.

42. The apparatus of claim 38, wherein each said cyclone separator has a head which has the largest cross-sectional area of said separator, said head having a radial clearance with said housing which is smaller than the diameter of said second manifold, said second manifold having a configured portion disposed between said head and said housing which is a non-circular cross-section.

43. The apparatus of claim 42, wherein said configured portion has a flow area which prevents restricted flow of the disposed liquids through said manifold between said head and said housing.

44. The apparatus of claim 42, wherein the cross-sectional area of said head is at least 30 per cent of the cross-sectional area of said housing.

45. The apparatus of claim 42, wherein the cross-sectional area of said head is at least 50 per cent of the cross-sectional area of said housing.

46. The apparatus of claim 38, wherein said housing includes a tubular wall having a plurality of apertures therethrough.

47. The apparatus of claim 46, wherein said apertures are located adjacent the formation.

48. A method of separating a recovery liquid and a disposal liquid from mixed liquids produced in a well, comprising the steps of:

disposing a cyclone separator down hole in the well;

packing off the well below the separator;

producing mixed liquids from the well above the packer;

flooding the area around the cyclone separator with mixed liquids;

flowing mixed liquids into the cyclone separator;

separating the recovery liquid from the mixed liquids;

flowing the recovery liquid to the surface; and

disposing the disposal liquids below the packer.

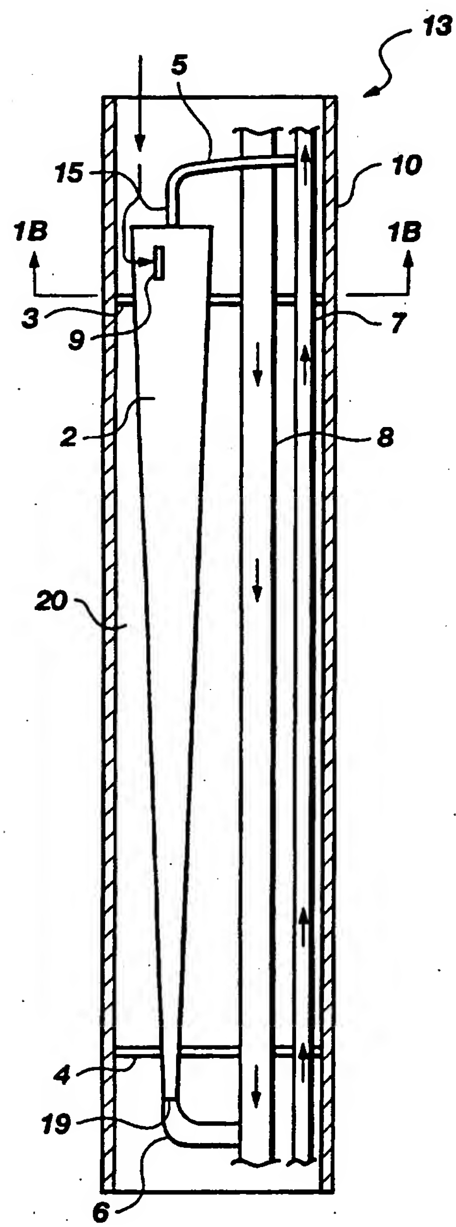

Fig. 1A

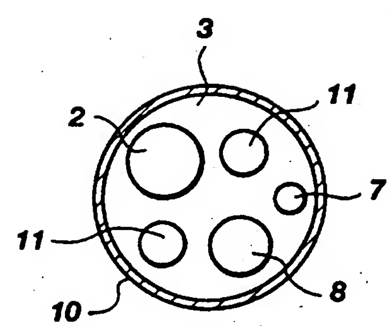

Fig. 1B

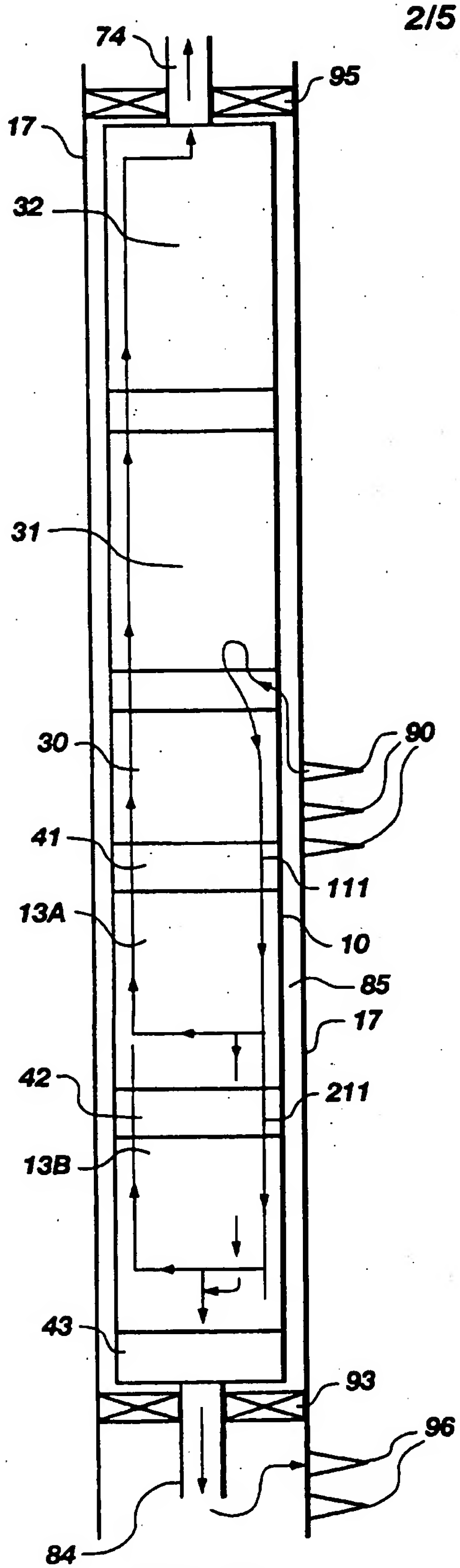

Fig. 2A

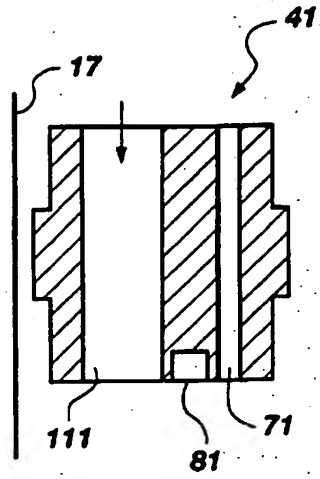

Fig. 2B

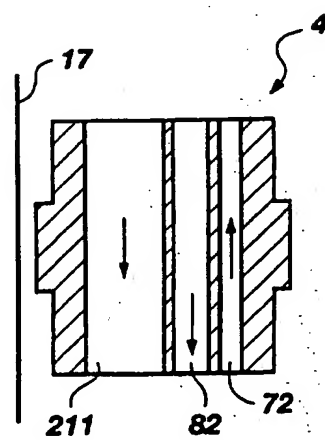

Fig. 2C

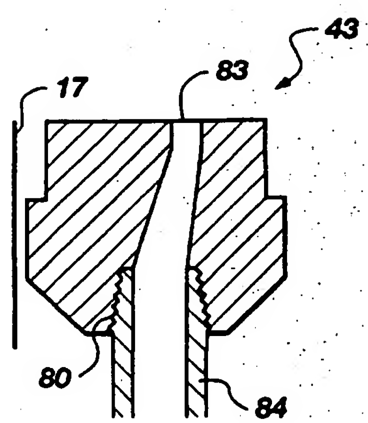

Fig. 2D

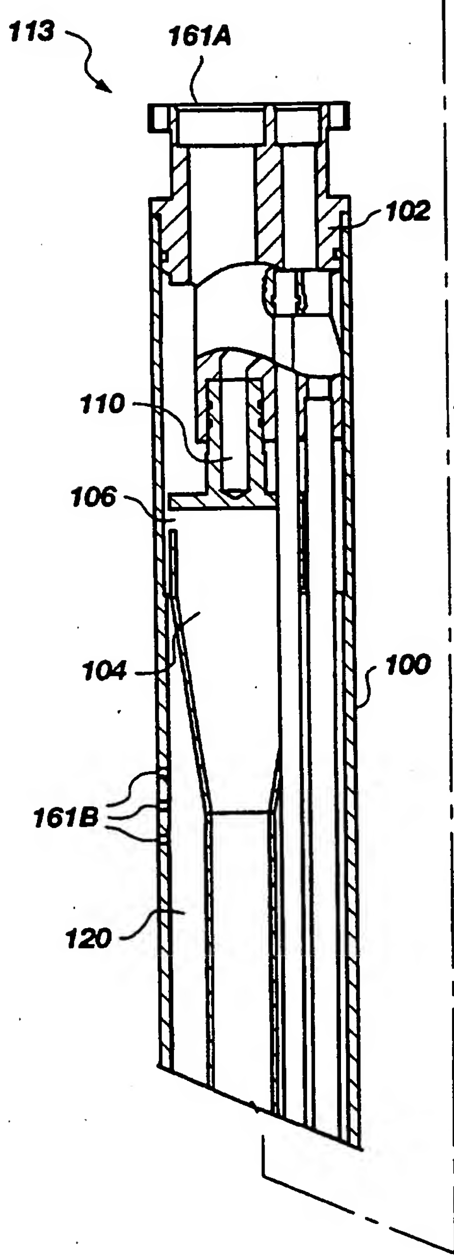
113
161A
102
110
106
104
100
161B
120

Fig. 3A

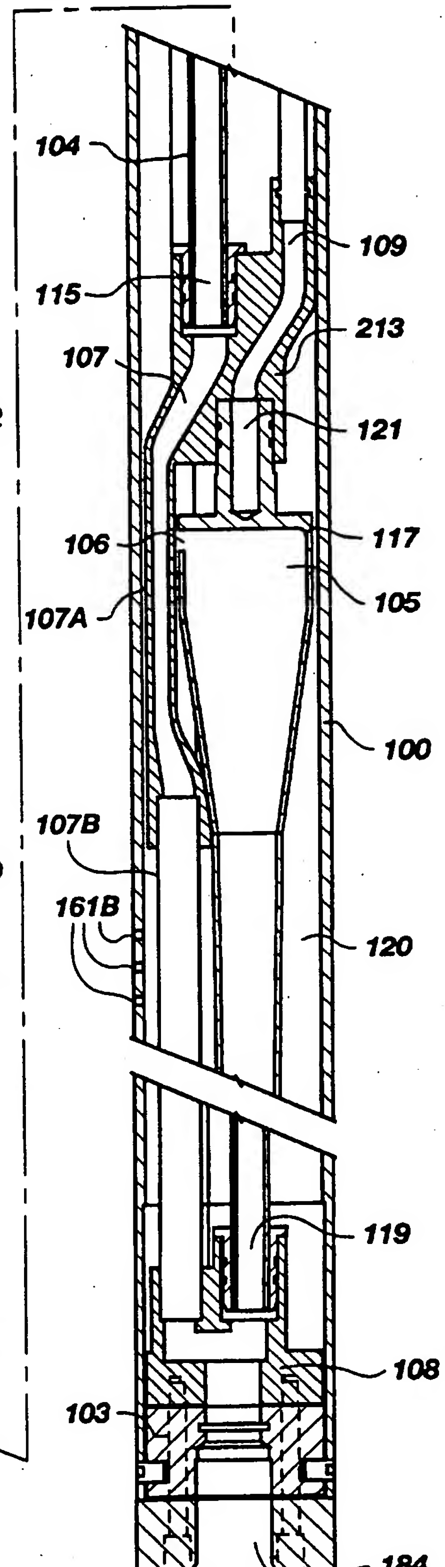
104
109
115
213
107
121
106
117
105
107A
100
107B
161B
120
119
108
103
184

Fig. 3B

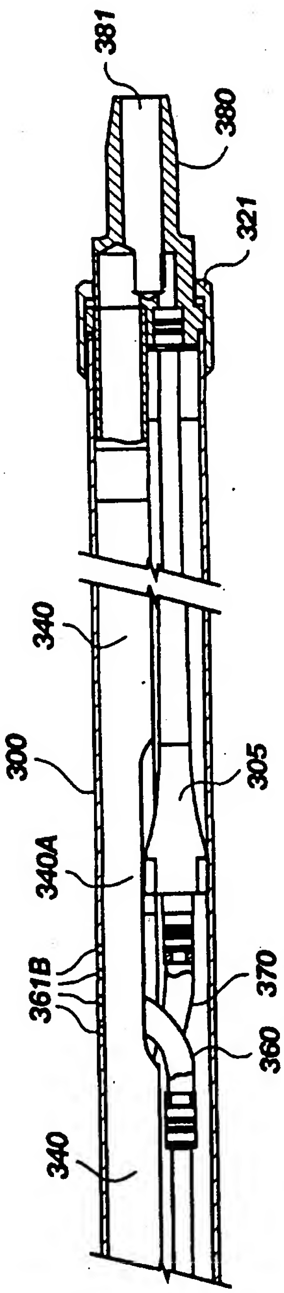

FIG. 4C

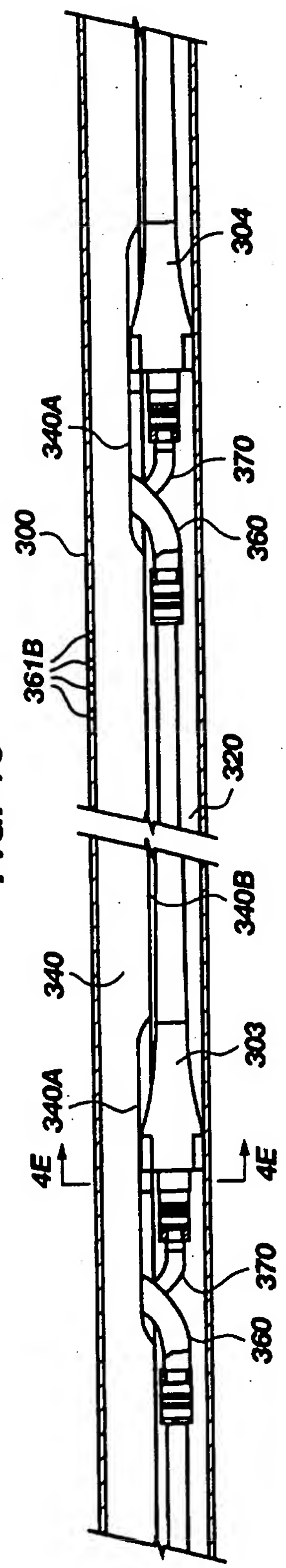

FIG. 4B

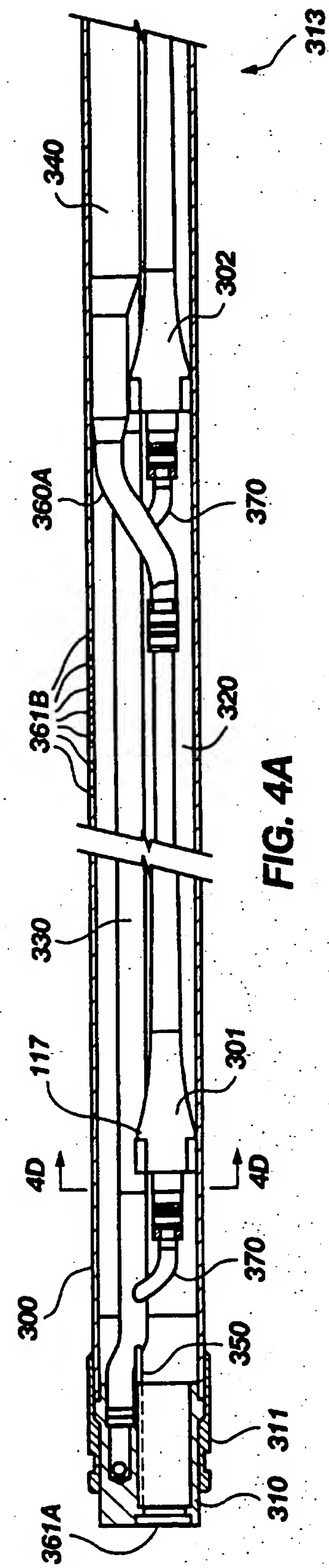

FIG. 4A

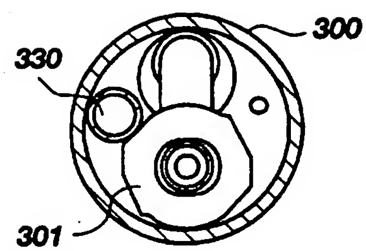

FIG. 4D

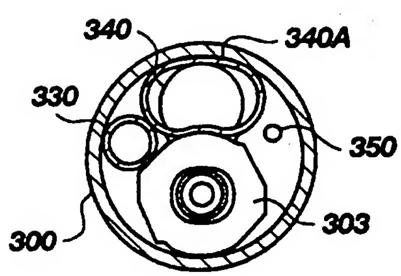

FIG. 4E

INTERNATIONAL SEARCH REPORT

International Application No
PCT/GB 97/00087

A. CLASSIFICATION OF SUBJECT MATTER IPC 6 B04C5/00 B04C5/081 B04C5/28 E21B43/38
According to International Patent Classification (IPC) or to both national classification and IPC
B. FIELDS SEARCHED
Minimum documentation searched (classification system followed by classification symbols) IPC 6 B04C E21B B01D
Documentation searched other than minimum documentation to the extent that such documents are included in the fields searched
Electronic data base consulted during the international search (name of data base and, where practical, search terms used)

C. DOCUMENTS CONSIDERED TO BE RELEVANT

Category *	Citation of document, with indication, where appropriate, of the relevant passages	Relevant to claim No.
X	WO 94 13930 A (READ PROCESS ENGINEERING A/S) 23 June 1994 cited in the application see abstract see page 7, line 7 - page 8, line 29; figures	35,38, 41,46-48
A		1,15-18, 24,25, 30,36

-/--

[X] Further documents are listed in the continuation of box C.

[X] Patent family members are listed in annex.

* Special categories of cited documents :

"A" document defining the general state of the art which is not considered to be of particular relevance

"E" earlier document but published on or after the international filing date

"L" document which may throw doubts on priority claim(s) or which is cited to establish the publication date of another citation or other special reason (as specified)

"O" document referring to an oral disclosure, use, exhibition or other means

"P" document published prior to the international filing date but later than the priority date claimed

"T" later document published after the international filing date or priority date and not in conflict with the application but cited to understand the principle or theory underlying the invention

"X" document of particular relevance; the claimed invention cannot be considered novel or cannot be considered to involve an inventive step when the document is taken alone

"Y" document of particular relevance; the claimed invention cannot be considered to involve an inventive step when the document is combined with one or more other such documents, such combination being obvious to a person skilled in the art.

"&" document member of the same patent family

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Date of the actual completion of the international search	Date of mailing of the international search report
23 May 1997	06. 06. 97
Name and mailing address of the ISA European Patent Office, P.B. 5818 Patentlaan 2 NL - 2280 HV Rijswijk Tel. (+ 31-70) 340-2040, Tx. 31 651 epo nl, Fax: (+ 31-70) 340-3016	Authorized officer Van der Zee, W

Form PCT/ISA/210 (second sheet) (July 1992)

INTERNATIONAL SEARCH REPORT

International Application No
PCT/GB 97/00087

C.(Continuation) DOCUMENTS CONSIDERED TO BE RELEVANT

Category *	Citation of document, with indication, where appropriate, of the relevant passages	Relevant to claim No.
X	US 5 296 153 A (PEACHEY) 22 March 1994 cited in the application see column 3, line 65 - column 4, line 66 see column 5, line 33 - line 34 see column 5, line 49 - line 50 see column 6, line 5 - line 6 see column 6, line 27 - column 28; figures	35,36,48
Y		38
A		1,5,6,9, 12-14, 18,24, 25,30,41
X	US 5 456 837 A (PEACHEY) 10 October 1995 see column 3, line 53 - column 5, line 27; figures	35-37
Y		38
A		1,5,6,8, 9,14,15, 18,24, 25,30, 41,48
A	US 4 688 650 A (HAYATDAVOUDI ET AL) 25 August 1987 see column 3, line 43 - line 65 see column 5, line 21 - line 30 see column 6, line 8 - line 17 see column 6, line 39 - line 43; figures	1,15,18, 24,36,38
A	WO 89 11339 A (CONOCO SPECIALTY PRODUCTS INC.) 30 November 1989 see abstract see page 8, line 24 - page 9, line 17; figures	1,15,17, 18,24, 36,38

1

INTERNATIONAL SEARCH REPORT

Information on patent family members

International Application No
PCT/GB 97/00087

Patent document cited in search report	Publication date	Patent family member(s)	Publication date
WO 9413930 A	23-06-94	NO 924896 A	20-06-94
		AU 5721194 A	04-07-94
		CA 2152070 A	23-06-94
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